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EARTHSHINE OBSERVATIONS FROM SOFIA UPPER DECK

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ABSTRACT

The Earthshine Project re-invigorated a method that holds the potential to observe our planet on a global scale, as it would be viewed from a very distant point. By measuring the light reflected from the bright and dark sides of the Moon, we can observe the Earth by means of astronomical techniques. We have determined annual changes in the Earth's global reflectance, in the 0.4-0.7μm range; with an accuracy of 1.0%. These data are significant inputs for climatic global circulation models (GCM). Now we intend to extend these measurements to the near-infrared region, for which stratospheric observations will be essential. In this presentation, we will discuss the importance of doing photometry of the near-infrared earthshine from the upper deck of the Stratospheric Observatory for Infrared Astronomy, as well as the required instrumentation. Earthshine's spectroscopy with the facility instrumentation is also proposed.

INTRODUCTION

We have been measuring Earth's reflectance by observing the light of the Earth reflected from the Moon (earthshine) since 1998 (Goode et al., 2001). For our observations we are using a 15 cm telescope attached to the 65cm Solar Telescope in Big Bear Solar Observatory (BBSO). The advantage of measuring the terrestrial albedo by observing the earthshine arises from the capability of obtaining long-term, global-scale information by means of relatively simple instrumentation. These data require a meticulous analysis (see Qiu et al. 2003 and Pallé et al. 2003 for details) but the finally achieved accuracy is difficult to obtain by any other method. Measurements from the BBSO station have allowed us to determine seasonal variations of the global albedo, to establish a relationship between the albedo and observed clouds properties from ISCCP satellite data, and to construct from the latter a proxy measure of the Earth's global reflectance in the visible range (Pallé et al., 2004b). We have determined from this proxy large albedo variations with important implications for climate change.

Similar studies need to be done in the infrared region, as explained in the following section. Observations from the stratosphere (above 75% of the atmosphere) will be critical to reduce the effect of the local atmosphere, in particular of the water vapor column, which effects are correctable in the visible, but are much more significant in the near infrared.

SCIENTIFIC CASE

Our climate has varied as the Sun has evolved since the formation of the solar system. In more recent eons, climate changes have been attributed to variations in the Earth's orbital parameters along with geological events that modify the concentration of greenhouse gasses. However, the physical mechanism(s) responsible for the increase of the globally averaged Earth's land and sea surface temperature during the last century remains unclear, and its anthropogenic origins un-quantified.

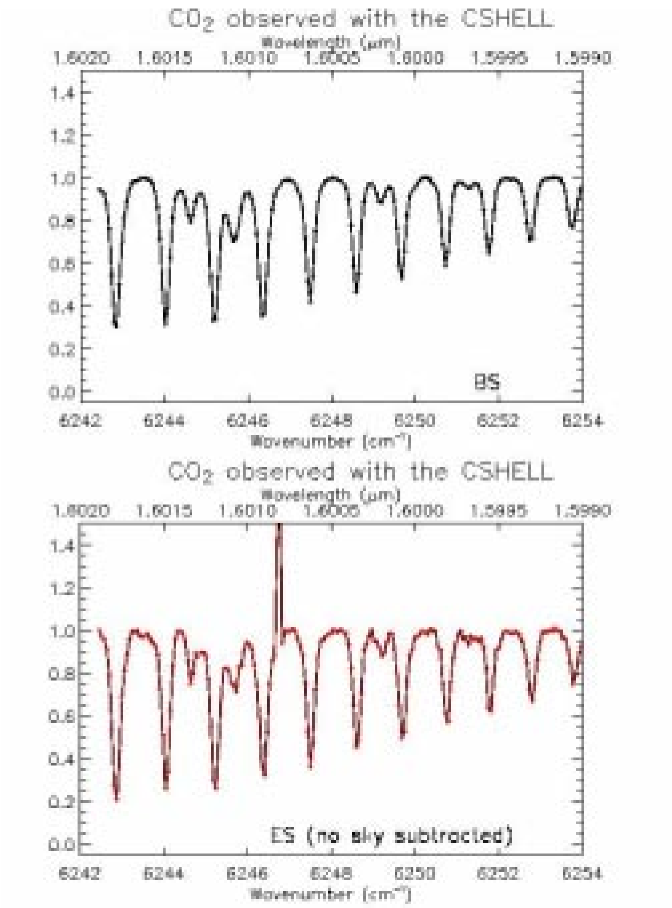

Fig. 1. CO_2 band (1.6μm) in the near-infrared for moonshine (BS) and earthshine (ES). Data were taken at the IRTF facility. Scattered light from the local atmosphere has not been corrected from the earthshine.

The climate is driven by the redistribution of the Sun's energy over the Earth's surface. Variations in the incident energy over time, or variations in the balance of this energy, will have consequences for the Earth's climate. The Sun's irradiance has been precisely measured from space for more than twenty years. Some fluctuations have been detected, but they are insufficient to explain the temperature increase of about half a degree centigrade of the last century. The Earth's bond albedo is another relevant variable into the Earth Radiation Budget (ERB) that used to be considered as a constant mean value of 0.3 until recently. By doing relative photometry from BBSO we have determined annual changes on the Earth's bond albedo, in the 0.4-0.7μm spectral region, with an accuracy of 1.0%.

Currently, as a complement to our photometric measurements in the visible, we aim to extend these observations to the near infrared (1-5μm). As climate evolves, these measurements may be able to identify significant changes due to processes such as cloud feedback and greenhouses forcing. Clouds have been proved to play an important role in climate change (Pallé et al., 2004), however their effects in the infrared region need to be quantified. Main greenhouses gasses (H_2O and C_2O) act by retaining Earth's energy in this region, thus we are not considering their forcing in our observations in the visible.

Expanding the earthshine observations to the near-infrared will lead not only to a better understanding of the ERB, but also to quantify the role of anthropogenic greenhouses in climate.

Other indirect goals that will be accomplished from stratospheric earthshine observations will be the establishment of an empirical database of terrestrial biomarkers in the near infrared, in support of future bioastronomy missions, and a precise measurement of the lunar surface reflectivity of interest for other astrophysical proposes.

We also intend to observe the near infrared earthshine through spectroscopy. We have started to explore this spectral region by observing with the Infrared Telescope Facility (Montañés Rodríguez et al. 2004b), Figure 1. By means of these observations with the SOFIA facility instrumentation, large-scale measurements of greenhouse species abundances such as CO_2 (1.538μm), CH_4 (1.667μm), or H_2O (1.12μm) will also be possible.

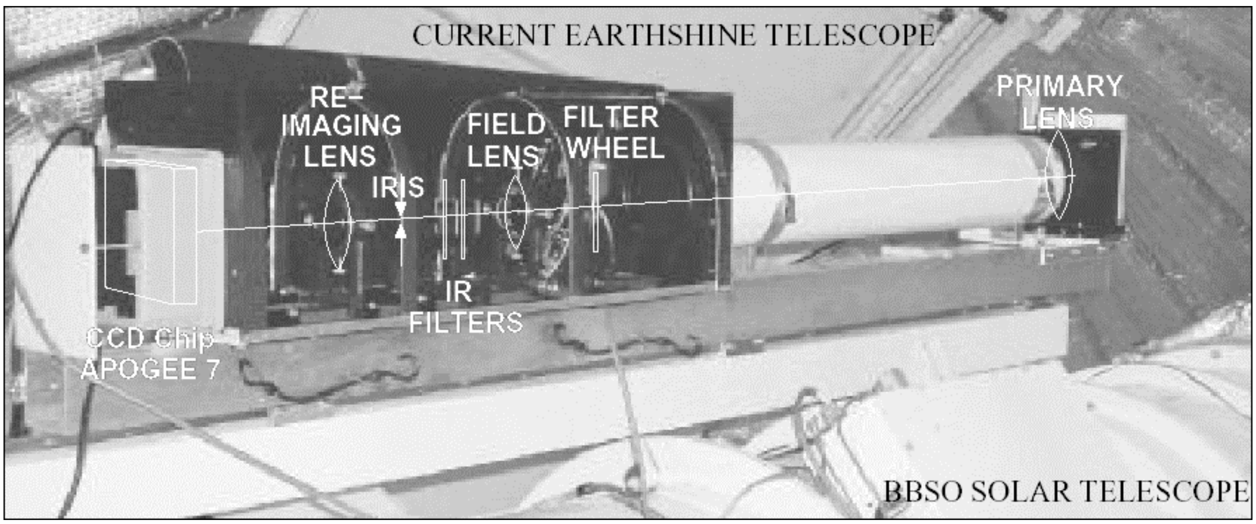

Fig. 2. Actual design of the earthshine telescopes. A more compact semi-automatic reflector network is being developed, and one of these stations may be adapted to observe from SOFIA upper deck.

INSTRUMENTATION

By observing the earthshine from one station we are measuring changes in the Earth's annual bond albedo in the visible at global scales, covering _ of the terrestrial sphere. Earthshine visible observations have recently been expanded to a three telescopes network, which will allow us to determine seasonal variation in bond albedo, and an 8 stations robotic network is being designed to improve this temporal resolution.

These robotic stations are envisioned as semi-automatic reflectors, to be located in nighttime astronomical observatories at 45 degrees intervals around the world. But, in parallel to the development of these stations, the optical design of an additional one may be adapted for near infrared observations, and its control and tracking software modified to be operated from SOFIA. Their semi-automatic quality, as well as their more compact design makes one of these stations ideal to be installed in the SOFIA upper deck.

METHODOLOGY

In our measurements from ground stations it is necessary to carry out several corrections due to the perturbation of the local atmosphere. For this, we observe the moonshine (the light reflected from the bright side of the Moon) and then we occult the bright side and observe the earthshine (dark side). This cycle is repeated during a night while the moon is above the horizon, in order to extrapolate to zero (top of the atmosphere) airmass. In the optical and with our current design, each of these observing cycles takes about two minutes. During the analysis, the nearby sky is subtracted from the earthshine images in order to eliminate the scattered light from the moonshine.

When observing from SOFIA, the extrapolation to zero airmass and the sky subtraction, our primary sources of error, will not be necessary. Our observations will not need to cover airmass variation. For each night, the required observing time may be reduced to a few cycles BS-ES, and even considering that the integration time for the near infrared will be longer than for the visible, several series will be accomplished within less than an hour. These data will provide a good quality measurement of the near-infrared effective albedo for the night.

In addition, our observing dates from the ground are restricted by the lunar phase. A too bright moonshine produces too much scattered light, and when the Moon is waning its time in the sky decreases preventing a precise airmass correction for lunar phases near new moon. These two limits will be considerably reduced when observing from the stratosphere, where our restrictions will just be due to the geometry of our fiducial patches, enhancing our lunar phase coverage. This enhancement will imply a larger Earth's surface coverage with only one station.

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